Solarcon Solar Concentrator Applied to Electric Propulsion

SRS Technologies
Huntsville Alabama

Naval Research Laboratory
Washington, DC

Advanced Space Propulsion Workshop
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How Solarcon Overcomes the Problems that Short-Circuit Electric Propulsion

Problem #1

- Power Requirements for Orbit Transfer by Electric Propulsion May Be Significantly Above the Power Requirements for the Spacecraft Once It Reaches Its Station
  - The Additional Cost and Weight of Solar Arrays Is an Argument Against Electric Propulsion

Solution

- Solarcon Can Double Array Power With Negligible Change in Weight and Cost

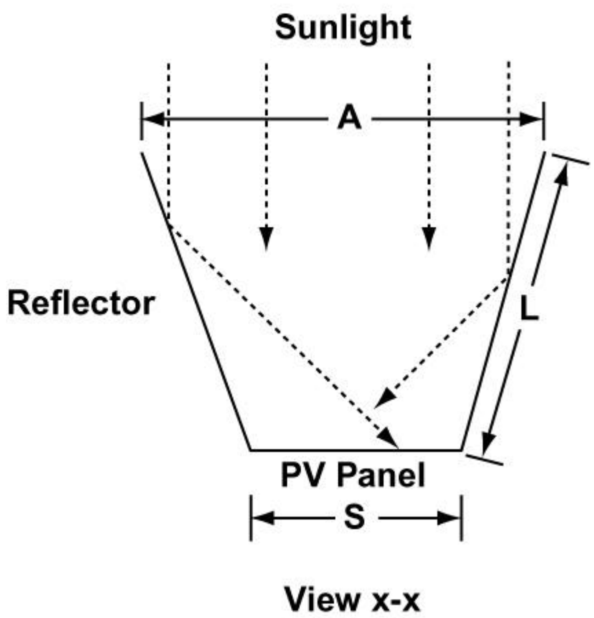
Problem #2

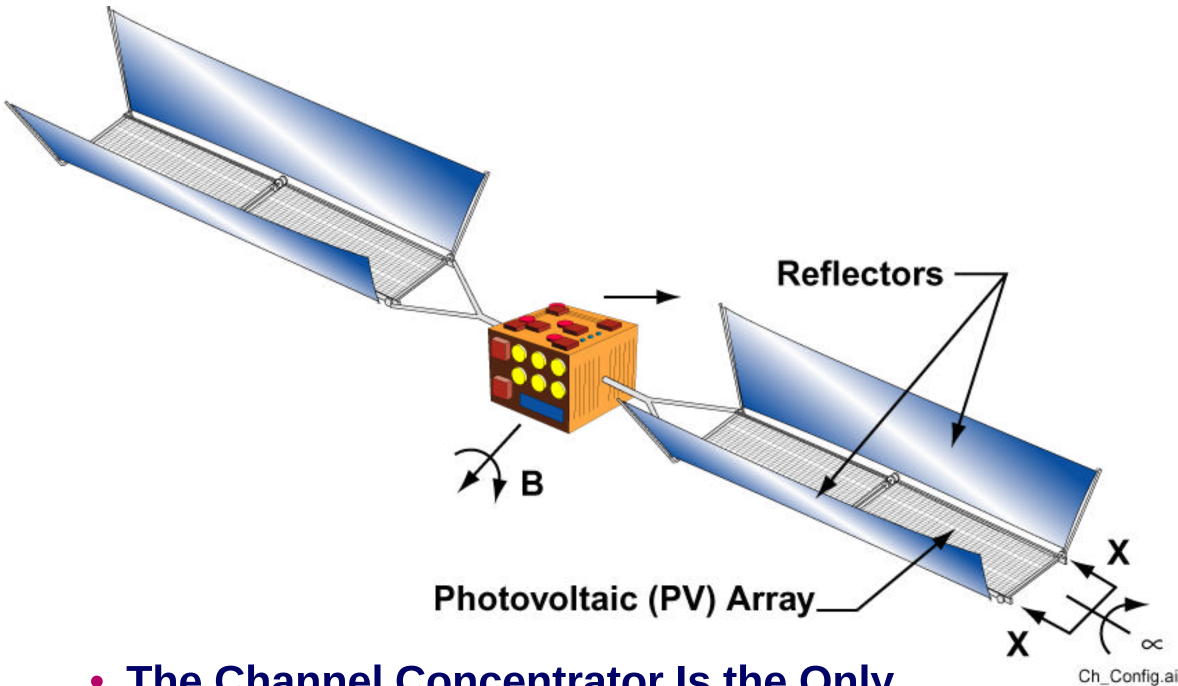
- Spacecraft Builders Have Rejected Previous Concentrators for Several Reasons: Risk, Net Efficiency, Novelty

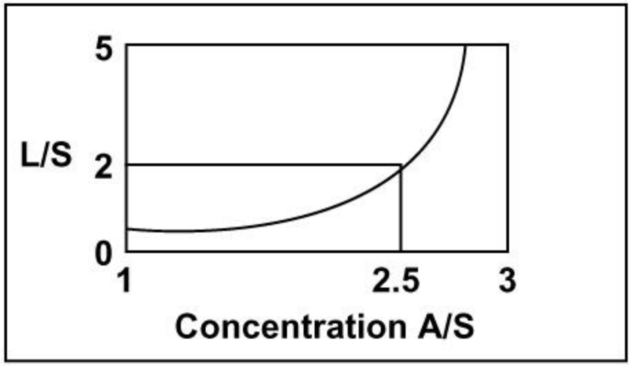
Solution

- Solarcon's Channel Configuration Generate Power When Stowed or If the Spacecraft Tumbles
- Solarcon Doubles Specific Power of a Given Photovoltaic Array
- Solarcon Uses Existing Solar Array Panels and Deployment Mechanisms – Stows in ½ the Volume of a Plane Array of Same Power

Channel Configuration Concentrator Definition





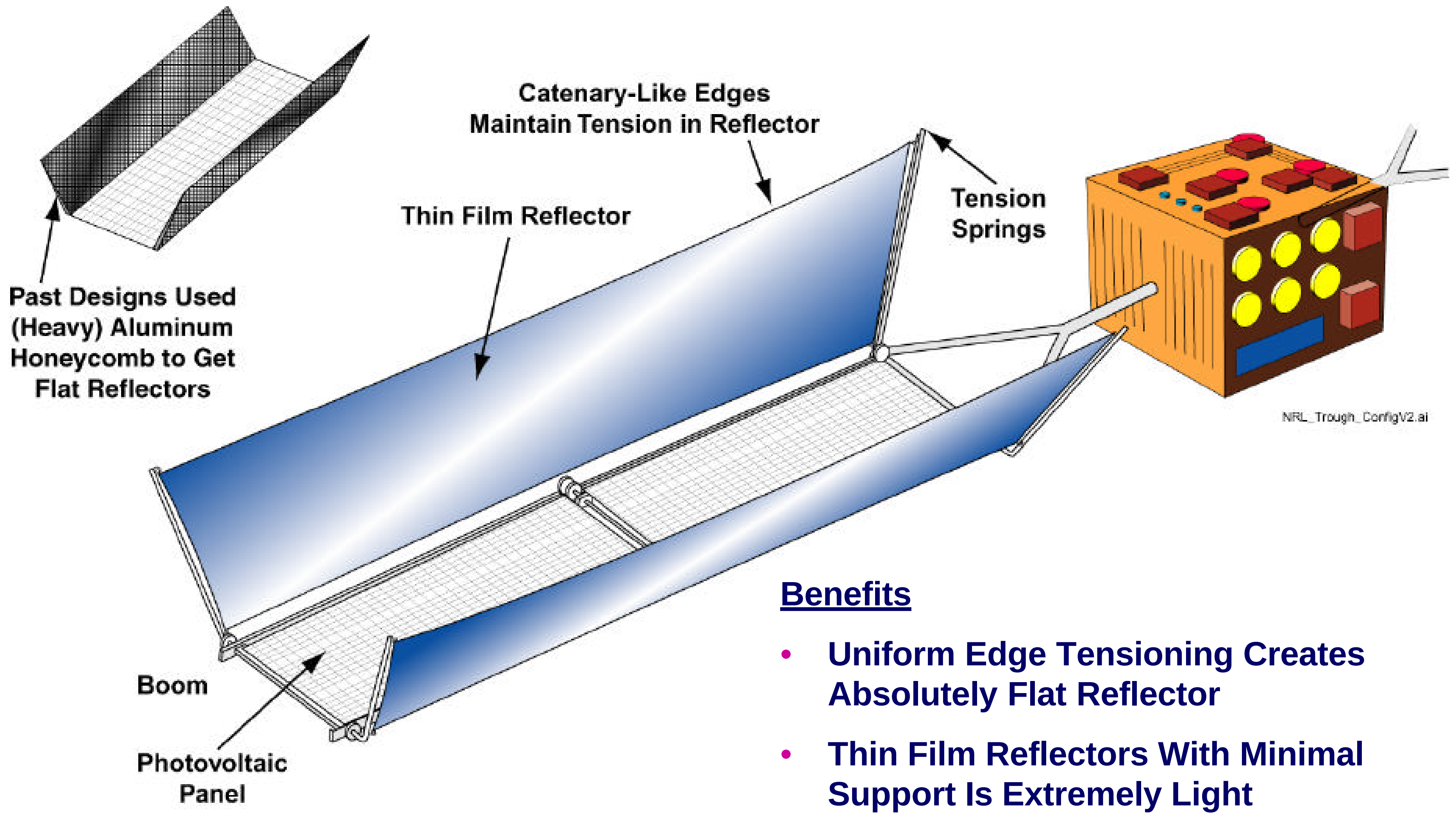


Geometric Concentration Ratio = A/S

- The Channel Concentrator Is the Only Configuration That Provides Power in the Stowed Configuration and If the Spacecraft Tumbles
- The Channel Configuration Uses Two Flat Reflectors to Focus Sunlight onto the Photovoltaic Array
- Practical Limit of Geometric Concentration Ratio (GCR) Is » 2.5:1 in Channel Design
- The Reflectors Must Be Optically Flat Since Uneven Sunlight on a String of Cells Degrades Power Output

NRL's "Solarcon"
Channel Concentrator Innovations

Innovation #1: Thin Film Reflectors With Catenary-Like Edges

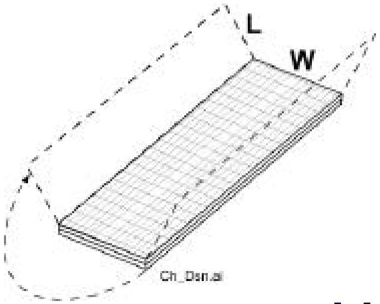


Benefits

- **Uniform Edge Tensioning Creates Absolutely Flat Reflector**
- **Thin Film Reflectors With Minimal Support Is Extremely Light**

NRL Channel Concentrator Innovations

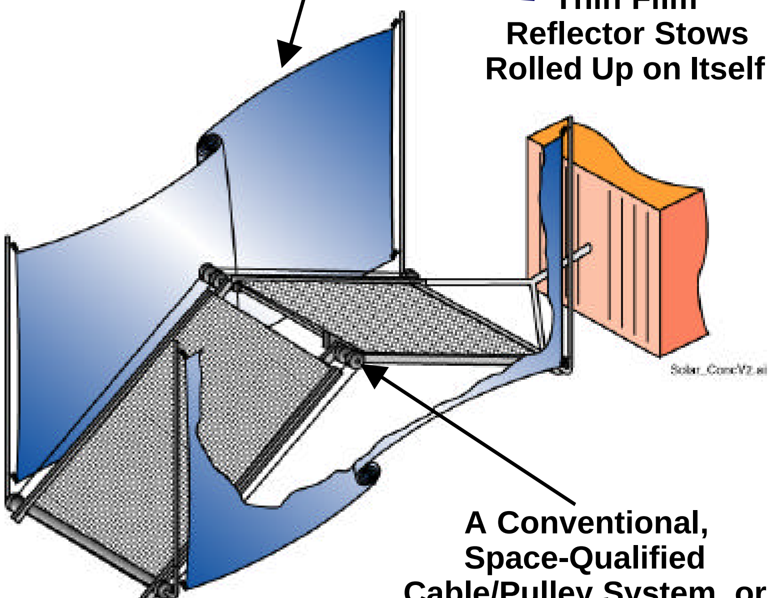
Innovation #2: Stow Reflectors Rolled-Up, Either Side of Solar Panel Stack



Other Channel Designs Stow Reflectors Behind Solar Panels
L £ W
\ GCR £ 2:1

Mid-Deployment

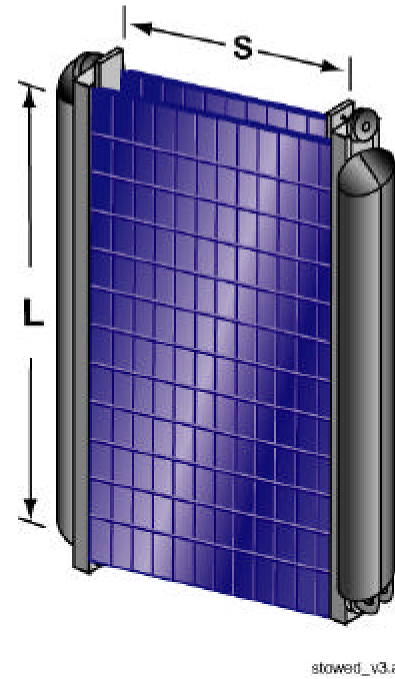
Thin Film Reflector Stows Rolled Up on Itself



A Conventional, Space-Qualified Cable/Pulley System, or a Four-Bar Linkage, Keeps the Booms Parallel During Deployment

Canted Axis Causes Boom to Rotate to Required Angle Theta

Stowed



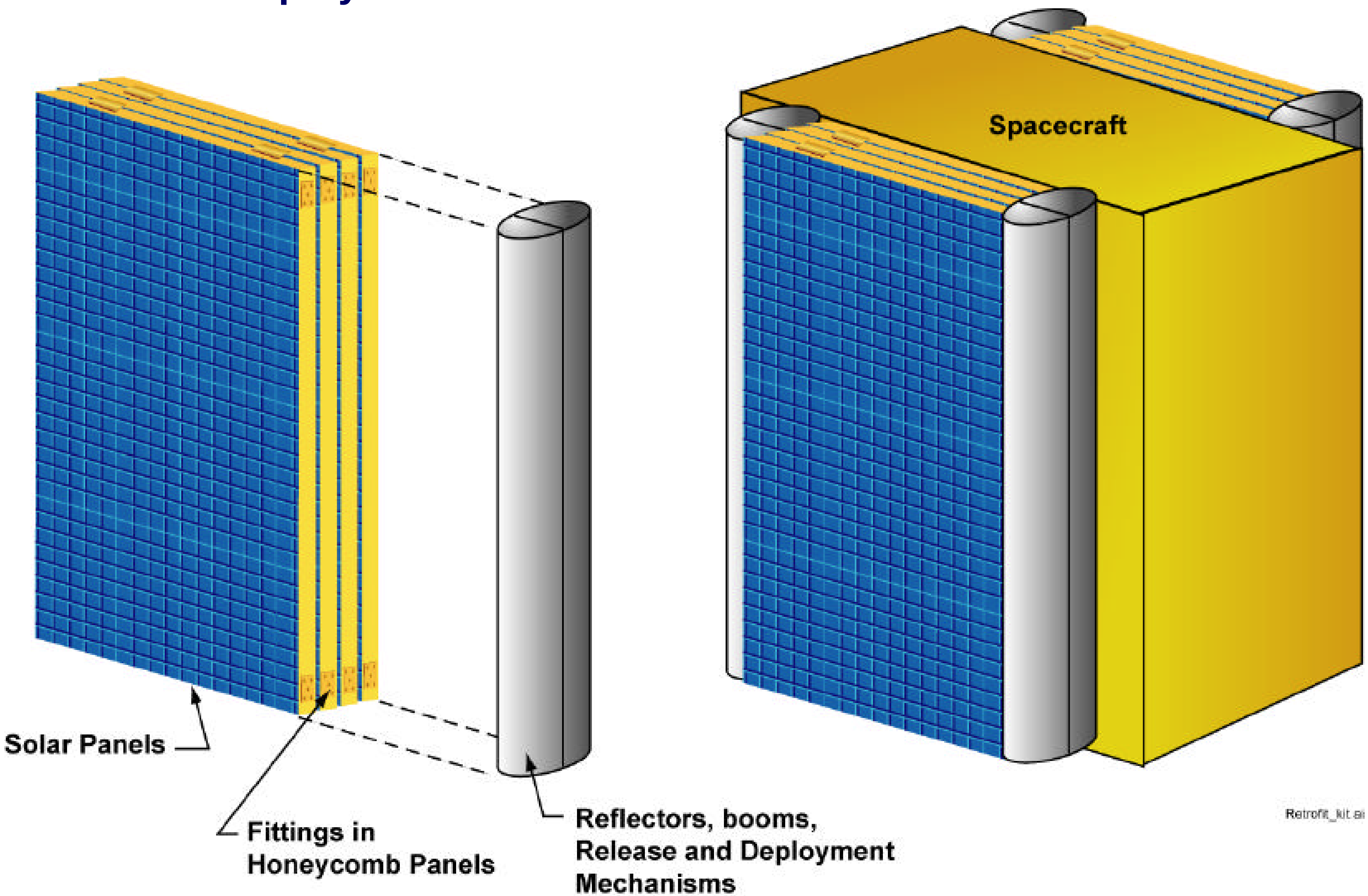
Reflectors Stowed in Canister/Booms

Benefits

- **Full Solar Panel Exposed in Stowed Position**
- **Since L>S, Maximum GCR of 2.5:1 Can Be Achieved**
- **Has Appearance of Conventional Solar Panels, Stows With ½ the Volume**

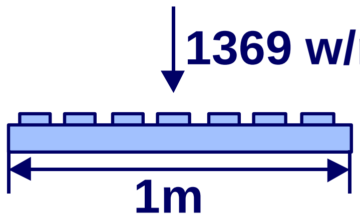
Innovation #3: Solarcon Retrofit Kit

- **Purpose: Allow Spacecraft Builders to Make Their Own Panels, Panel Deployment Mechanisms. . .**



Solarcon Doubles Specific Power of an Unaugmented Solar Array

1. Unaugmented Array



90% Packing Factor

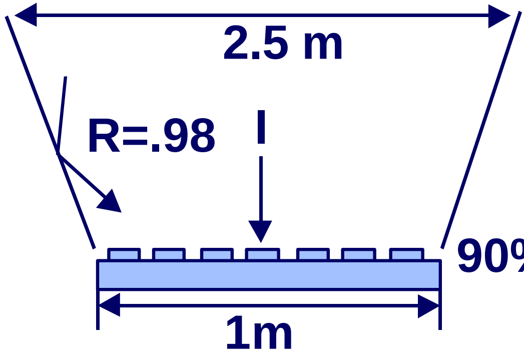
Cell: 21.7% at 70° C

Large Array: 71.5 w/kg (Tecstar)

Power: 1369 w/m^2 * .217 * .9 =262.4 w/m^2

Mass: $\dfrac{262.4\ w/m^2}{71.5\ w/kg} = \dfrac{3.66\ kg}{m^2}$

2. Solarcon



90% Packing Factor

Cell: 19.3% at 120° C

I: 1369w/m^2 * (1 + 1.5 * .98) = 3381.4 w/m^2

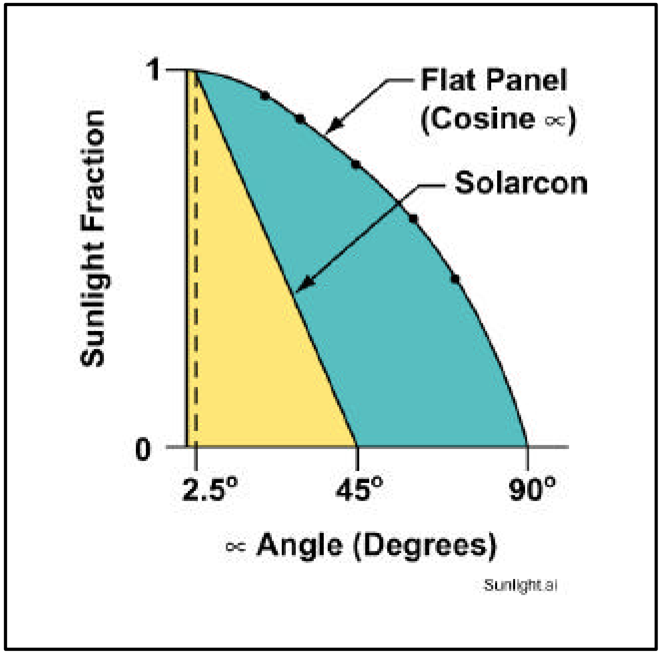
Power = 3381.4 w/m^2 * .193 * .9 =587.4 w/m^2

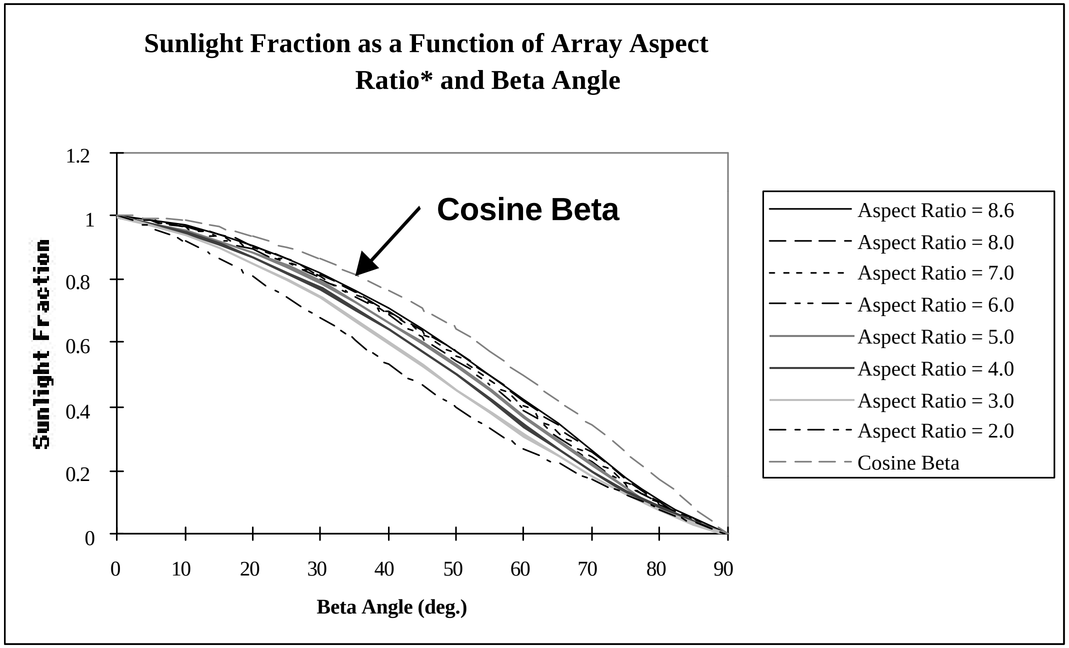
3. Allowable Reflector System Mass for 100% Increase in Specific Power

$$\frac{587.6\ w/m^2}{2 * 71.5\ w/kg} = 4.167\ kg/m^2\ \text{Goal}$$

- 4.167 kg/m^2 – 3.66 kg/m^2 (Unaugmented) = $\dfrac{.44\ kg\ \text{Reflector System}}{1\ m^2\ \text{Solar Panel}}$
- 4m^2 Reflectors/1m^2 Solar Panel *0.0176 kg/m^2 Reflector = $\dfrac{0.0704\ kg\ \text{Reflector}}{1\ m^2\ \text{Solar Panel}}$
- Balance for Booms, Deployment Mechanisms = .44 kg - .07 kg = .37 kg/m^2 Panel

Solarcon Off-Pointing Efficiency





*** Aspect Ratio Is Array Length Divided by Width**

- **Alpha Variation Shown for Beta = 0 Degrees**
- **Does Not Defocus With B Variation**
- **Maximum Theoretical Sunlight Fraction May Be Reduced by Uneven Distribution of Light on Cell Strings**
- **Assumes 100% Reflectivity (Actual Is ~95%-98%)**
- **Provide 13% of Full Power When Tumbling About µ Axis**

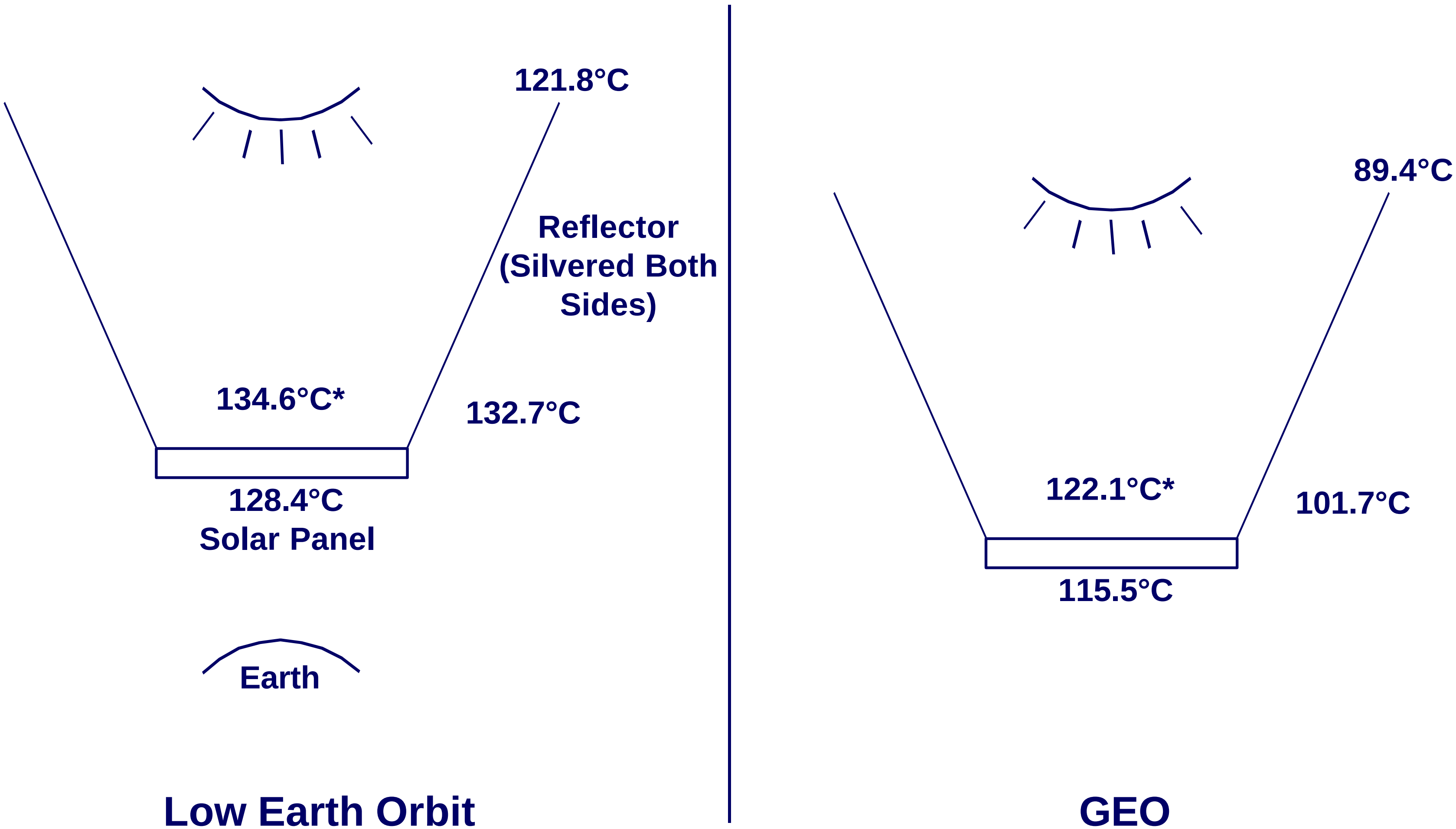
Micrometeorites Induce Only Minor Reflector Damage

- Evaluation Performed on Flightlike Reflector Panels
  - Loaded to Operating Stresses (30 psi Then, ~ 3 psi Now)
  - Metallized 0.5 Mil Clear Polyimide (CP1) and Kapton Foils
- Bombarded With Aluminum Spheres
  - 16 Mil and 125 Mil Diameter at 6.8 Km/Sec
  - Normal Incidence Angle
- Exposure Created "Clean" Holes in Reflector - No Ripping or Other Propagated Damage Observed
- Negligible Electrical Output Degradation Since Damage Is localized
- Knife Cut in Stressed Reflector Did Not Propagate

Thin Film Reflector Will Operate in Space Environment

- **Atomic Oxygen**
  - **No Issue in Benign GEO Environment**
  - **SiO_2 Coating Provides Foil Protection in LEO**
- **Ultraviolet Radiation**
  - **Metallized Clear Polyimide (CP1) Film Preferred to Kapton**
  - **Negligible CP1 Degradation Expected Due to Brittleness and/or Darkening**
- **Environmental Characterization Efforts Continuing**
  - **Aerospace Corp. UV Measurements Complete 12/97**
  - **NASA to Initiate Activity Supporting the Next Generation Space Telescope (Thin Film Sunshade)**

Solarcon Operating Temperatures

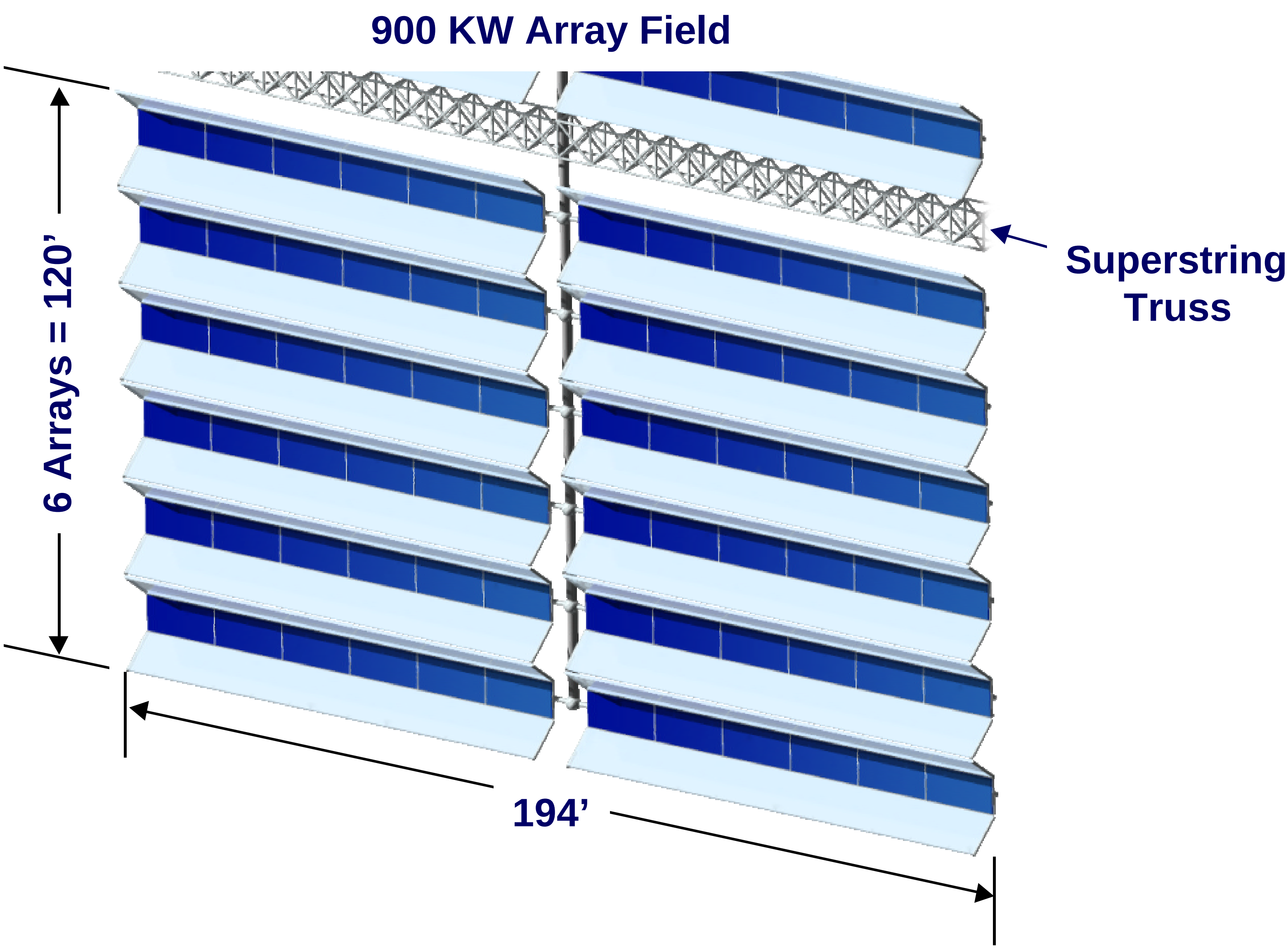


*** Tecstar (Cell Manufacturer) States That This Temperature Is Acceptable for Long Term Operation**

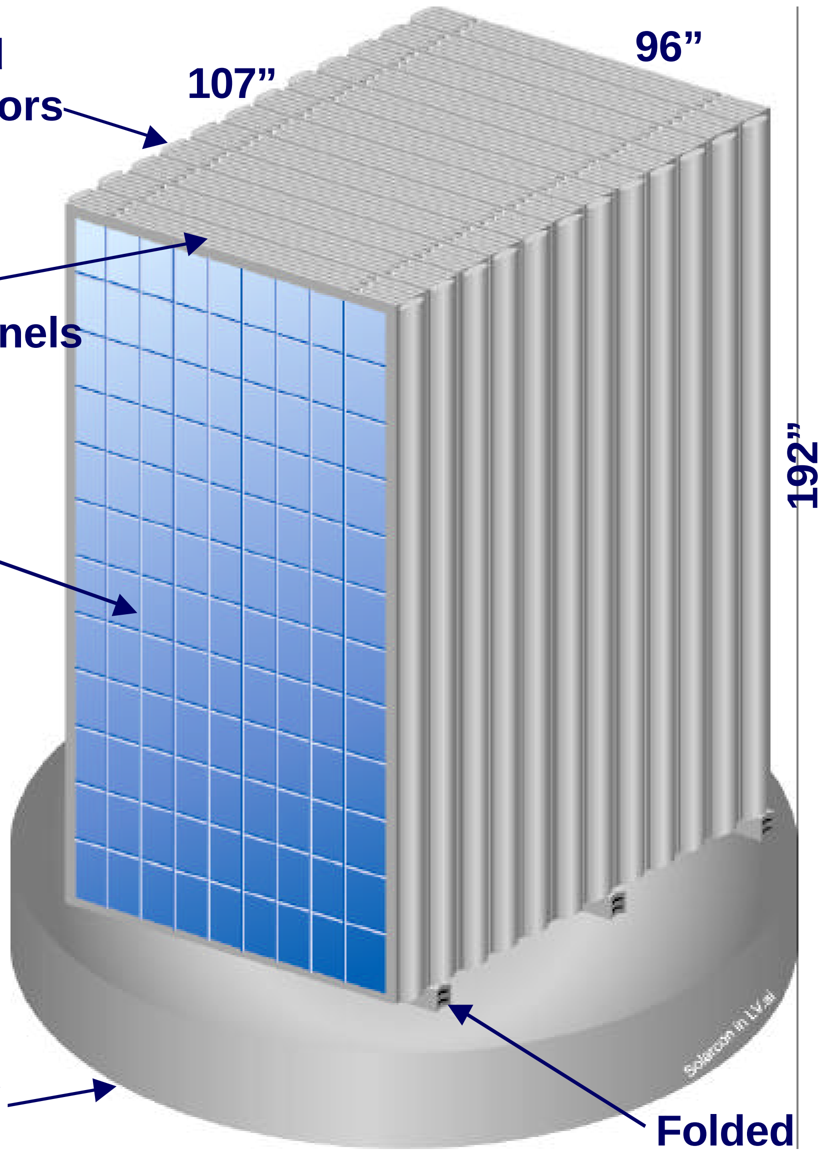
Solarcon Reflector Material Development

- The Reflector Material Is CP1, Manufactured by SRS of Huntsville, Alabama
- CP1 Is a Fluorinated Polyimide With Exceptional UV Resistance, Thermal Stability, Transparency, and Solubility
- CP1 Was Developed by NASA/Langly and SRS Holds the Sole License to Produce This Material
- CP1 Is Easily Soluble
  - It Can Be Cast on Many Different Surfaces With Varying Thickness Down to 0.1 mil
  - It Produces Films That Are Optically Flat With Isotropic Material Properties and Exhibits no Residual Stress
- 220C Maximum Operating Temperature
- Life Predictions
  - Successful Aerospace Corporation Accelerated Life Test for 5 Years in LEO Followed by 5 Years at GEO
  - Qualified by GSFC for Use on Hubble
  - Accepted by Hughes for Extended Life at GEO
- SRS and Langly Are Developing Techniques to Cast the Reflective Silver With the Polyimide So Reflectivity Cannot Be Decreased by Physical or Chemical Contact

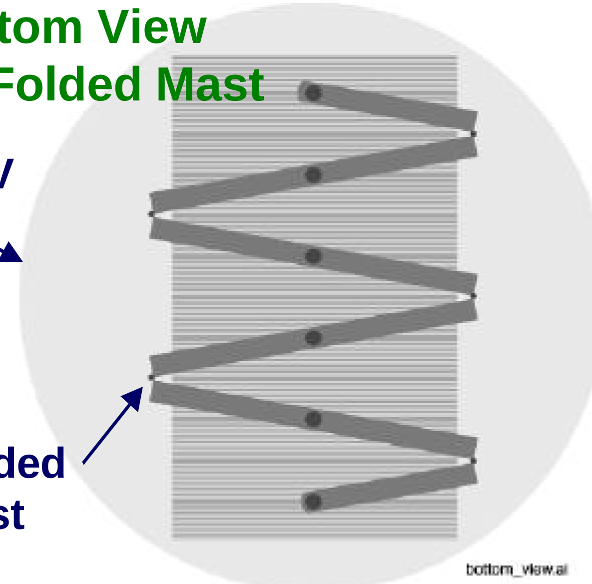
Solarcon Example: Building Space Power Generator at Geo With Electric Propulsion



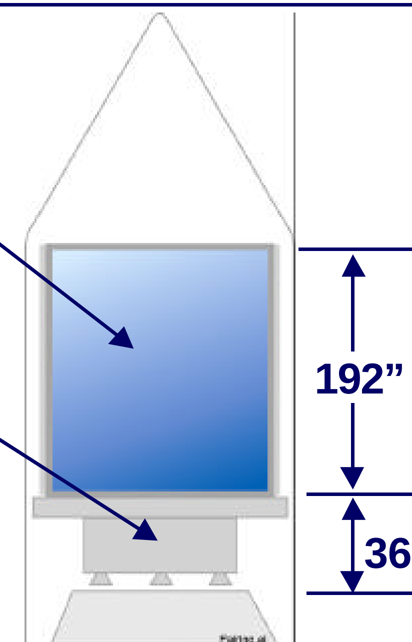
Solarcon 900 KW Array Field in Launch Vehicle



Stack Bottom View Showing Folded Mast

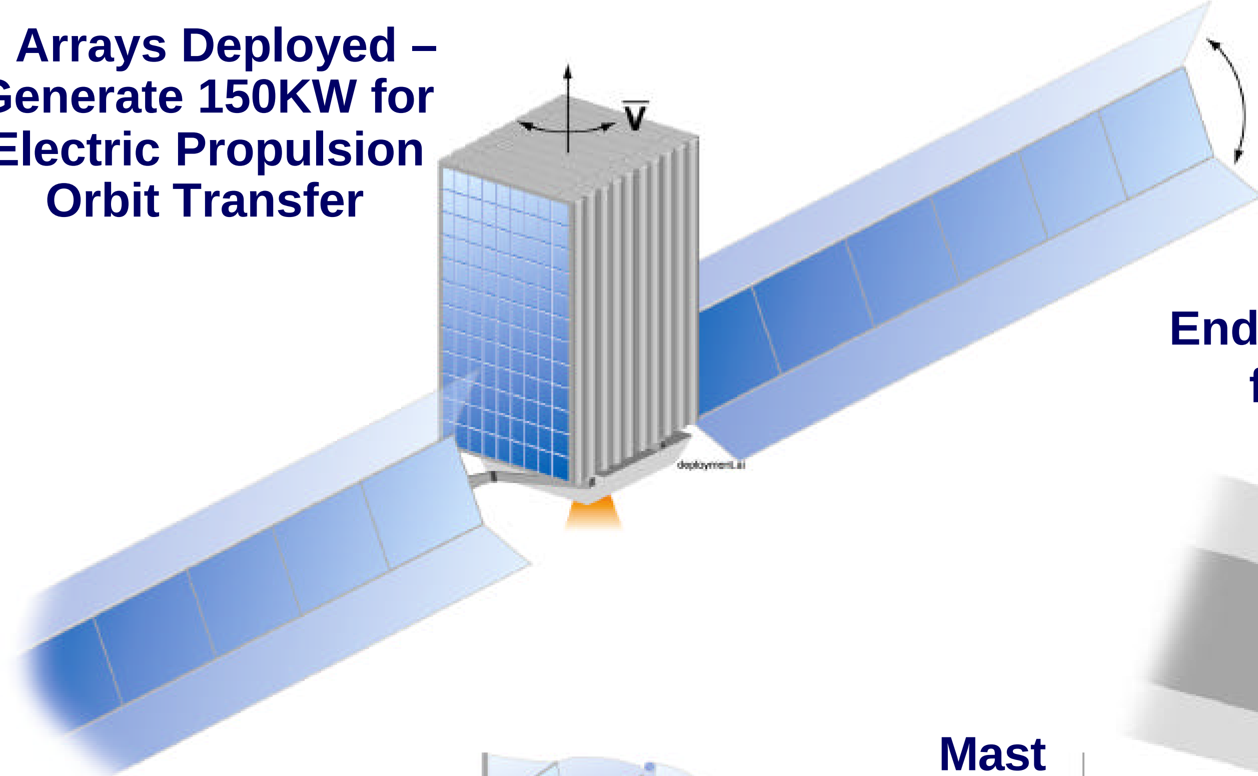


D-IV Fairing

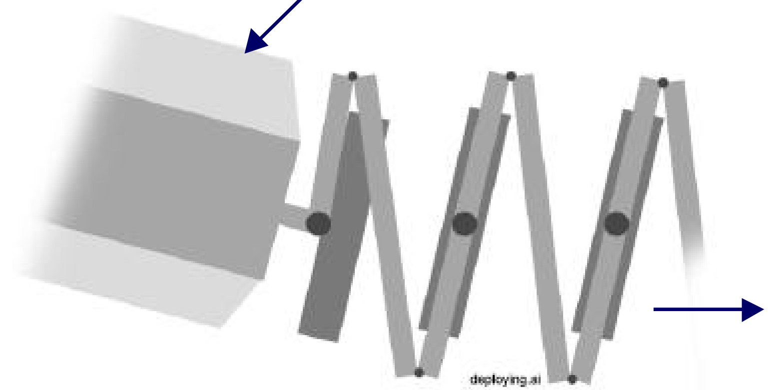


Solarcon 900 KW Array Field Propelling Itself to Geo

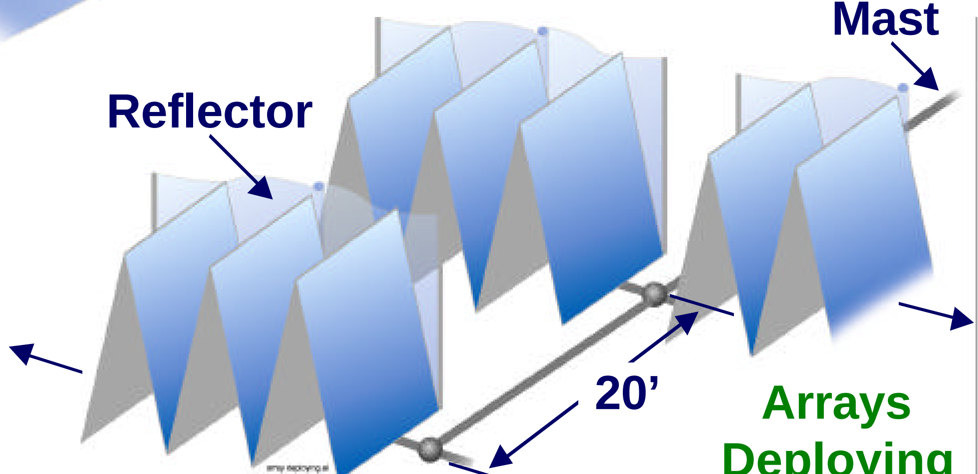
2 Arrays Deployed – Generate 150KW for Electric Propulsion Orbit Transfer



End Arrays Already Deployed for Electric Propulsion



Bottom View – Array Field Starting to Deploy



Example: Transporting Solar Array Field to Geo Case 1

- All Chemical Propulsion
- 300 N mi Circular at 28.7° to 19,323 N mi Circular at 0° - ΔV=13,641 ft/sec

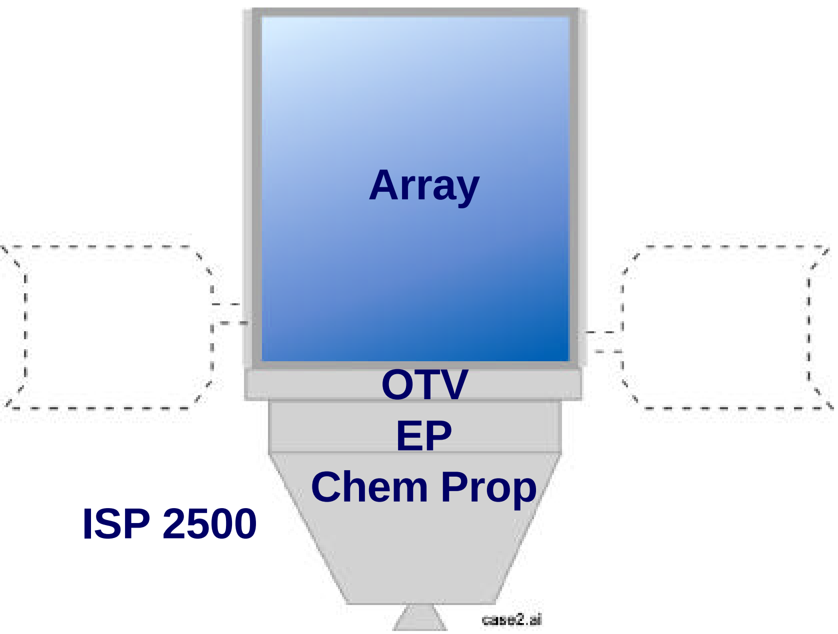
ISP 444

900 KW Array Field	10,000#
OTV (Guidance, Comms…)	300
Propulsion System	2778
Propellant (H_2 O_2)	20988
Total to LEO	34,066#*
Today's Technology Total to LEO:	42,087#

*Predicted Future Technology

Example: Transporting Solar Array Field to Geo Case 2

- **Chemical Propulsion 300 N mi to 4,000 N mi Circular at 28.7° - DV= 7,029 ft/sec**
- **Electrical Propulsion to 19,323 N mi Circular at 0° - DV= 13,323 ft/sec (40 Days)**



900 KW Array Field
10,000#

OTV
300

EP System – 150 KW, 1.79# Thrust
2778

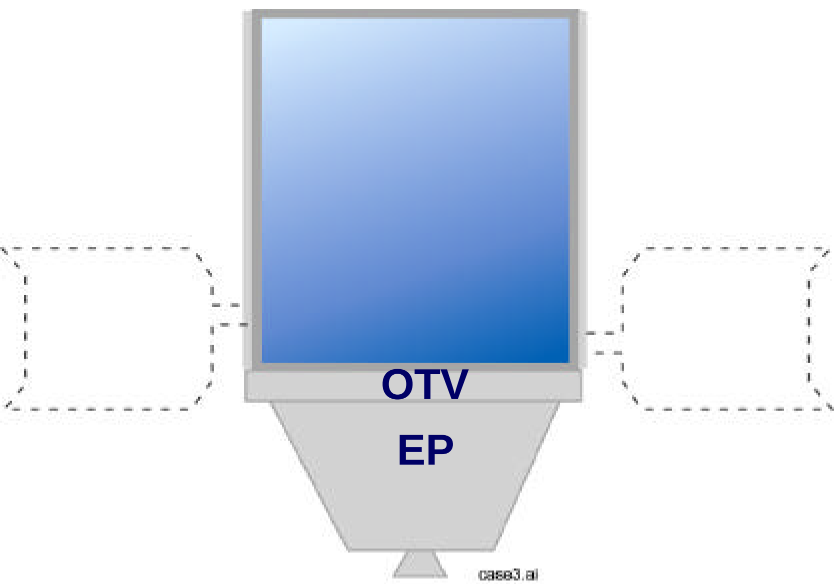
EP Propellant
2076

Chemical Propellant System
1311

Chemical Propellant
9701

Example: Transporting Solar Array Field to Geo Case 3

- **Electrical Propulsion 300 N mi Circular at 28.7° to 19,323 N mi Circular at 0° - DV= 19,136 ft/sec (62 Days)**



ISP 2500
Thrust = 1.79#

900 KW Array Field
10,000#

150 KW Propulsion Power Degrades to 133 KW in Van Allan Belts

OTV
300

EP System – 1.75# Thrust
1359

EP Propellant
3132

Total to LEO
14,791#

Impact of Array Efficiency Loss in Passing Through Van Allan Belts

- **150 KW Arrays (Deployed for Electric Propulsion) Degrade to 133 kw (89%)**
- **Loss of 17 kw Is Equivalent to 17,000w / 240 w/kg = 71 Kg Mass of Additional (Protected) Array Required to Make up Loss**